

SOURCES OF MAGNETIC HELICITY OVER THE SOLAR CYCLE

Volker Bothmer

Max-Planck-Institut für Aeronomie, D-37191 Katlenburg-Lindau, Germany, bothmer@linmpi.mpg.de

ABSTRACT

The magnetic field characteristics of a sample set of helical magnetic flux rope ICMEs (magnetic clouds) observed by the Wind and ACE satellites in solar cycle 23 and their related space weather effects are investigated. The solar source regions of the magnetic clouds were identified using remote sensing observations of the SOHO, Yohkoh and TRACE spacecraft together with ground-based H_α images. Each cloud observed at 1 AU could be uniquely associated with a well defined frontside halo CME some days before the cloud's arrival at 1 AU. The hemispheric origin is consistent with the expected hemispheric helicity pattern. The space weather effects of the clouds were quite variable, depending on their internal magnetic field configuration and speed of propagation.

1. INTRODUCTION

Satellite measurements made in the interplanetary medium have revealed the frequent occurrence of transient large-scale solar wind streams (with typical radial sizes of ~ 0.25 AU at 1 AU) that exhibit the internal field structure of helical magnetic flux ropes [e.g., 1, 2, 3, 4]. These low plasma- β flows are called magnetic clouds (MCs) and appear to be the interplanetary consequences of solar coronal mass ejections which are associated with disappearing filaments (prominence eruptions) [5, 6, 7]. It was found that MCs form a subset of all interplanetary coronal mass ejections (ICMEs) in the heliosphere, with those (both MC-like and non MC-like) ICMEs that propagate considerably faster than the ambient solar wind, driving collisionless shock waves [8, 9, 10, 11]. The reason why not all ICMEs exhibit a smooth rotation of the magnetic field direction characteristic of a helical flux rope (e.g., Fig. 1, 3 of [10]) is not known to date. There are a number of plausible reasons that could explain the difference in the in situ magnetic field properties: The magnetic structure of the solar source regions of ICMEs may be different for MC-like and non MC-like ICMEs; magnetic reconnection at the sun may lead to different magnetic topologies in CMEs; the coronal and interplanetary evolution may have altered the original magnetic field structure; the spacecraft's trajectory through an ICME may lead to different

signatures in case the large-scale flows are non-homogenous - especially when ICMEs are not hit centrally. The fraction of ICMEs being MCs ranges from about one third to about one half of all identified ICMEs [11, 12]. The ratio of ICMEs being helical is important to investigate questions about the sun's helicity budget and its possible variation over the solar cycle. Hence it is crucial to understand first the properties of MCs in the solar wind in more detail as well as their interplanetary evolution before concrete values for the helicity gauge or concepts such as helicity conservation in the solar system plasma are considered. It should be pointed out further, that magnetic helicity [13, 14, 15] as a measure for the "twistedness" of the magnetic field is defined as a conserved quantity for a closed volume V (for which the magnetic field \mathbf{B} can be expressed by the vector potential of \mathbf{A} in terms of $\mathbf{B} = \text{rot } \mathbf{A}$) as:

$$H = \int_V \mathbf{A} \cdot \mathbf{B} \, dV \quad (1)$$

The definition of magnetic helicity implies for the proper calculation of H , knowledge of the full 3D magnetic field topology. Conservation of helicity ideally requires a perfectly conducting plasma and force-free conditions as stated e.g., by Taylor [16]. It should be pointed out, that as long as the 3D field topology of MC and their source regions at the sun is not known, only premature estimates of helicity values can be obtained, a fact often not mentioned in helicity studies of coronal and interplanetary features [e.g., 17, 18]. It would of course be more appropriate to use the term magnetic chirality instead of magnetic helicity when the field structure of MCs is considered so that the title of this article also represents an oversimplification along this line of discussion. However, even with the given uncertainties, fundamental concepts have been derived empirically from the correlation of in situ and remote sensing observations to explain the magnetic features of MCs with respect to their source region field properties at the sun. In these concepts, the helicity variations brought along by CMEs and ICMEs play a key role in terms of the sun's magnetic field variations [19]. The fundamental principle to explain the field structure of MCs and their solar cycle variations has been introduced based on the associations of MCs with disappearing filaments [20, 21, 22, 23, 24]:

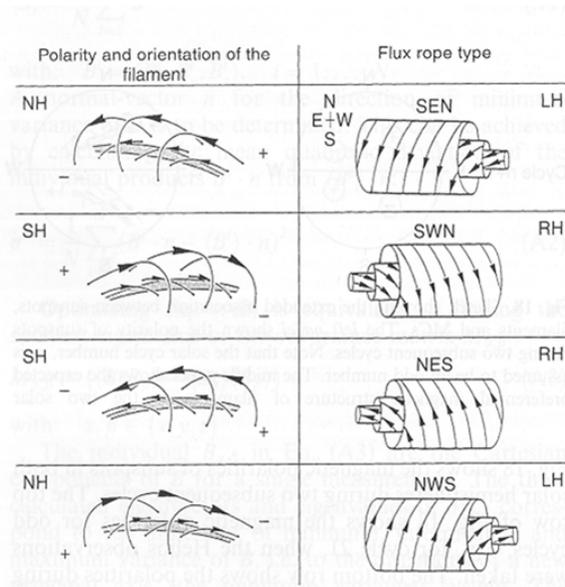


Fig. 2. Sketch showing the magnetic field structure of filament sites in the northern and southern solar hemispheres (left column) and the left- and right-handed (LH, RH) twisted MCs expected to be observed in interplanetary space in association with coronal mass ejections from these source regions. Adapted from [8, 3].

1) The magnetic field structure is predominantly left-handed twisted in the northern hemisphere and predominantly right-handed twisted in the southern hemisphere as viewed by an observer looking towards the sun [23, 24]; 2) The agreement of the field structure of MCs with those inferred for the associated filament sites [8, 3]. The applied scheme is shown in Fig. 1, adapted from Bothmer and Schwenn [8, 3].

Depending on the polarity of the magnetic field lines, which are forming an arcade above the filament's long axis, the typical orientations of neutral lines separating both magnetic polarities in the northern and southern solar hemispheres, the different MC types sketched in Fig. 1 are expected to evolve. Left-handed twisted MCs originate from filament sites with the depicted magnetic polarities in the northern hemisphere and right-handed twisted MCs originate from filament sites with the depicted polarity in the southern hemisphere. SEN, SWN, NES and NWS denote the field variations in GSE coordinates that an observer would measure when passing through the center of a horizontally directed MC with respect to the ecliptic. Note that the middle letter denotes the direction of the flux ropes axial field so that vertical to the ecliptic oriented MCs would lead to directional changes as ESW, WSE, WSE and WSE. Taking into account that the magnetic

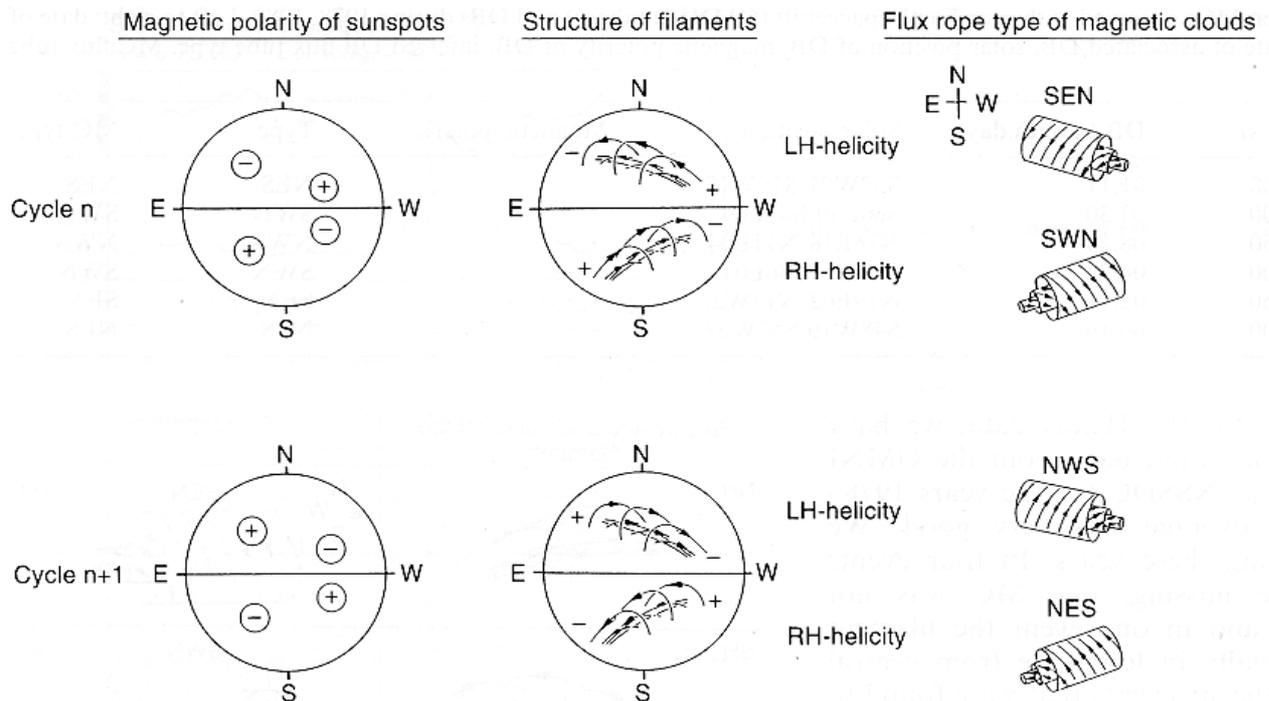


Fig. 1. Solar cycle dependence of the magnetic field structure of filaments at the sun and that of the corresponding MCs in the interplanetary medium. Adapted from [8, 3]. Note that for simplicity the MCs are oriented horizontally with respect to the ecliptic plane and that the cycles do not indicate any overlaps.

polarities and the inclinations of the neutral lines separating them follow Hale's and Joy's laws [e.g., 25] and that these properties are reflected in the typical orientation of filaments, Fig. 2 presents a plausible scenario to explain the reported solar cycle variation of the field structure of MCs [3, 22]. The systematic study of MCs observed by various satellites during different solar cycles had surprisingly revealed a predominance of MCs with southward directed fields in their leading edges, i.e. the outer circular field lines of large-scale cylindrically flux tubes or ropes as sketched in Fig. 1, and northern directed fields in their trailing edges in odd cycles (SN types), and a predominance for the opposite directions (NS types) in even cycles [3, 8, 26]. No LH or RH net-helicity has been found in these studies as expected if MCs would originate with the same probability from both solar hemispheres over a sufficiently long time interval analysed.

A simplification of Fig. 2 is that it does not take into account the phases during the solar cycle when magnetic regions of both the old and new cycle are present. During these overlapping time periods, disappearing filaments (erupting prominences) could lead to the origin of SN or NS fields in MCs.

The out of ecliptic orientation of the magnetic field direction carried by MCs and their solar cycle variation plays an important role in terms of space weather because a southward component is a key parameter to trigger geomagnetic storms (e.g., [27]). If the field structure of MCs is indeed a relict of the magnetic field structure of the solar source regions as suggested, then the above summarised concepts for MCs are of high importance for space weather prediction models.

For the current solar cycle 23 a unique set of spacecraft measurements of the solar wind at 1 AU from the Wind and ACE (Advanced Composition Explorer) satellites [27, 28, 29, 30, 31] as well as unique remote sensing observations from the SOHO (Solar and Heliospheric Observatory), Yohkoh and TRACE (Transition Region and Coronal Explorer) spacecraft allow to investigate the scenarios presented in Fig. 1, 2 in hitherto unprecedented quality. In the following section sample observations selected for this cycle are presented together with geomagnetic parameters to further investigate the following aspects of MCs: a) their internal field structure in cycle 23; b) their solar source regions; c) the source region's magnetic field properties; d) the hemispheric dependence of magnetic helicity; e) the related space weather effects.

2. SAMPLE OBSERVATIONS OF MCs IN CYCLE 23, THEIR SOLAR ORIGIN AND RELATED SPACE WEATHER EFFECTS

The following examples of ICMEs shall provide a brief glance on the properties of MCs in solar cycle 23.

More systematic studies are currently in progress [e.g., 32, 33]. The MCs presented here have been identified from an inspection of the Wind and ACE data. They are also part of the Wind and ACE magnetic cloud lists at the following internet sites: http://lepmfi.gsfc.nasa.gov/mfi/mag_cloud_table.html; http://www.barto.ludel.edu/~chuck/ace/ACElists/obs_list.html. For the sample events presented here, the solar source regions and related activity features were studied using SOHO, Yohkoh and TRACE observations. Filament disappearances were investigated by using H_{α} -measurements from the French spectroheliograph at Meudon.

2.1 RH twisted SWN cloud on January 10/11, 1996

The MC shown in Fig. 3 was detected by the Wind satellite on January 10/11 as a direct consequence of a frontside halo CME that was observed by SOHO/LASCO (Large Angle Spectrometric Coronagraph) on January 6, 1997 around 16 UT [34]. The speed of the CME was at the order of 450 km/s, comparable to the solar wind speed of the helical magnetic flux rope ICME detected at Earth's orbit. The magnetic field structure of the MC was that of a right-handed twisted one of type SWN (compare with Fig. 1, 2). The source region of the CME was identified by the SHINE group (http://umbra.nascom.nasa.gov/SHINE_report.html) near S24°W01° where a filament disappearance took place at ~13-14 UT on January 6. The source region of the CME is indicated by a circle in the SOHO/MDI (Michelson Doppler Interferometer) magnetogram presented in Fig. 4. The identified source

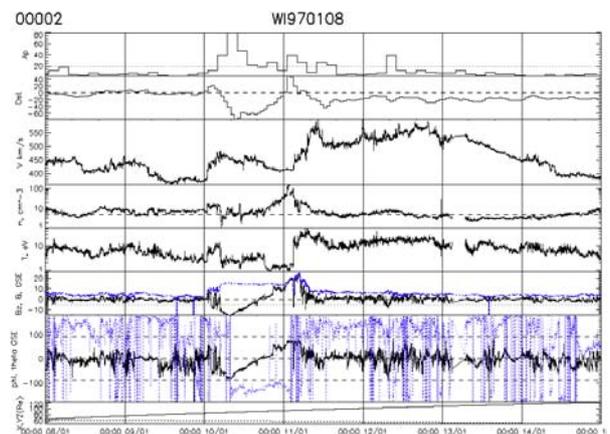


Fig. 3. Right-handed (RH) SWN-type magnetic cloud observed by Wind in January 1997. From top to bottom are displayed: Geomagnetic Ap- and Dst-values, solar wind speed, density and temperature, magnetic field magnitude B (dotted curve) and Bz-component (solid curve), latitudinal (θ , solid curve) and azimuthal (ϕ , dotted curve) angles of the field vector in GSE-coordinates.

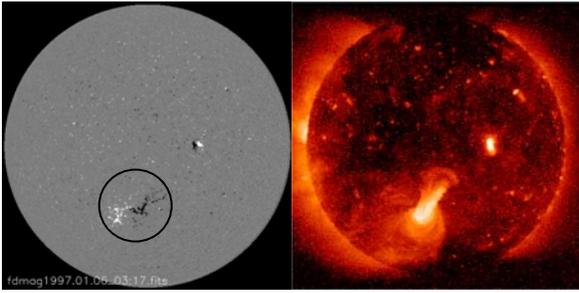


Fig. 4. SOHO/MDI magnetogram (left) and Yohkoh soft X-ray images (right) showing the source region (circle) of the January 6, 1997 CME. White colors in the magnetogram indicate positive magnetic polarity (field lines pointing away from the sun).

region of the MC is in agreement with the results of a systematic study of the source regions of CMEs by Subramanian and Dere [35]. In the MDI image, the positive (white) magnetic polarity (with field lines pointing away from the sun) is located East of the neutral line in the southern hemisphere. According to Fig. 1, a right-handed twisted flux rope of type SWN should have evolved from it, in agreement with the Wind observations (see also [34, 36]). The solar observations are thus in perfect agreement with the in situ ones concerning the magnetic field structure. The estimated axis orientation of the MC was found to lie almost parallel to the ecliptic plane with an inclination of less than 10° [32]. A minimum variance analysis (MVA) as described in [3] yields $\theta=+6^\circ$, $\varphi=71^\circ$ for the direction of intermediate variance (axis direction) in GSE coordinates for the time interval January 10, 06 UT to January 11, 02 UT. The angles θ and φ provide values for the inclination and azimuthal angle of the cloud axis with respect to the ecliptic. Compared to the degree of inclination of the neutral line of the source region, the cloud axis appears to be less inclined at 1 AU.

The highest geomagnetic disturbance levels during the passage of this MC at Earth orbit were associated with the southward field direction in the cloud's leading edge. Other remarkable features were the evidence of prominence material in the cloud's trailing edge and the loss of a satellite at times of its passage [32, 35].

2.2 LH twisted ENW MC on September 22, 1997

The axis of MCs can in principal have any orientation with respect to the ecliptic plane. Fig. 5 shows a MC observed by Wind on September 22, 1997 that was preceded by a shock on September 21. The geomagnetic activity was highest at the times following shock passage when the ICME's turbulent sheath was passed. The field configuration of the MC can be described as LH of type ENW. The directional changes of the field vector, with a northward directed

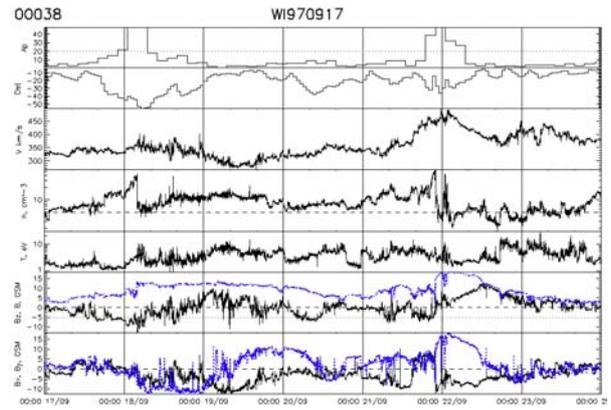


Fig. 5. A MC observed by Wind on September 22, 1997 and its related geomagnetic activity.

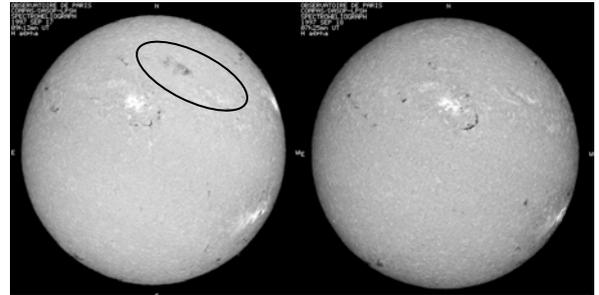


Fig. 6. A filament disappearance (circle) on September 17/18, 1997.

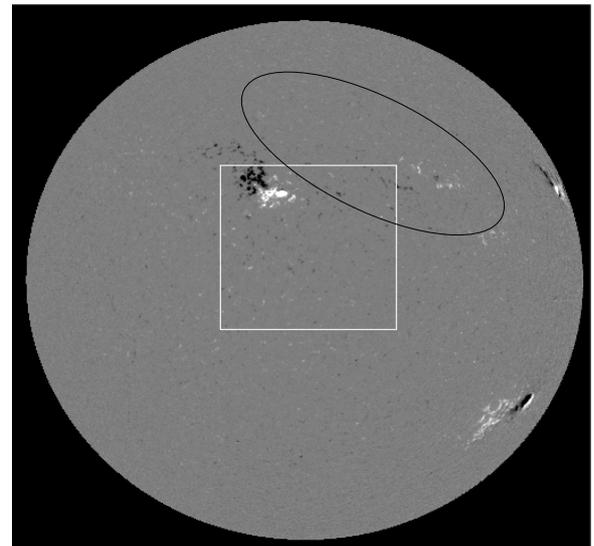


Fig. 7. MDI magnetogram taken on September 17, 1997. The circle denotes the position of a disappearing filament. The white box indicates the area at which high resolution measurements were recorded.

field at the cloud's axis caused the geomagnetic storm levels, that were triggered by passage of the sheath region behind the shock, to decrease. The results of the

MVA provide $\theta=63^\circ$, $\varphi=16^\circ$ for the time interval September 22, 05 to 18 UT, confirming the expected high inclination of the cloud axis. Based on the solar wind speed, the MC should have left the sun late on September 17 in agreement with the detection of a frontside halo CME at around 20 UT by LASCO/C2 (LASCO CME catalogue at http://cdaw.gsfc.nasa.gov/CME_list/) and the disappearance of a large H_α filament in the sun's northern hemisphere (Fig. 6). Images of the SOHO/EIT instrument showed a post-eruptive arcade system of coronal loops that had a substantial larger spatial extent than the disappearing H_α filament itself. This area is indicated by the ellipsoid in Fig. 7 in the MDI magnetogram taken on September 17. The magnetic polarity is found to be positive to the W of the neutral line, matching the expected flux rope type as suggested by Fig. 1, 2. Due to the inclination of the MC axis, it turned from a SEN rotation into an ENW one in agreement with a CW (clockwise) inclination of the axis as expected according to the location of the CME/filament source region neutral line (Fig. 7).

2.3 LH twisted SEN (ESW) type MC on April 16/17, 1999

The ACE satellite was encountered by a MC on April 16 to 17, 1999 as shown in Fig. 8. The time variation of the magnetic field shows a symmetric profile with peak intensity during the first half of April 17. The rotation of the magnetic field direction appears split up into the azimuthal angle φ (ESW) and the latitudinal angle θ (SEN). Based on the rotation one expects a highly inclined MC axis of type SEN. This is confirmed by the results of the MVA for the time interval April 16, 20 UT to April 17, 18 UT, yielding $\theta=+72^\circ$, $\varphi=4^\circ$. The slow speed MC should have left the sun early on April 13. LASCO/C2 detected a halo CME around 3 UT on this day. The halo was accompanied by a filament disappearance and post-eruptive arcade in the sun's northern hemisphere (Fig.

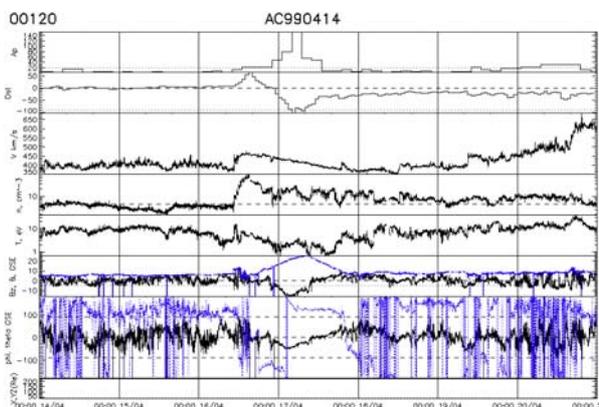


Fig. 8. A MC observed on April 16/17, 1999 by the ACE satellite and its related geomagnetic activity.

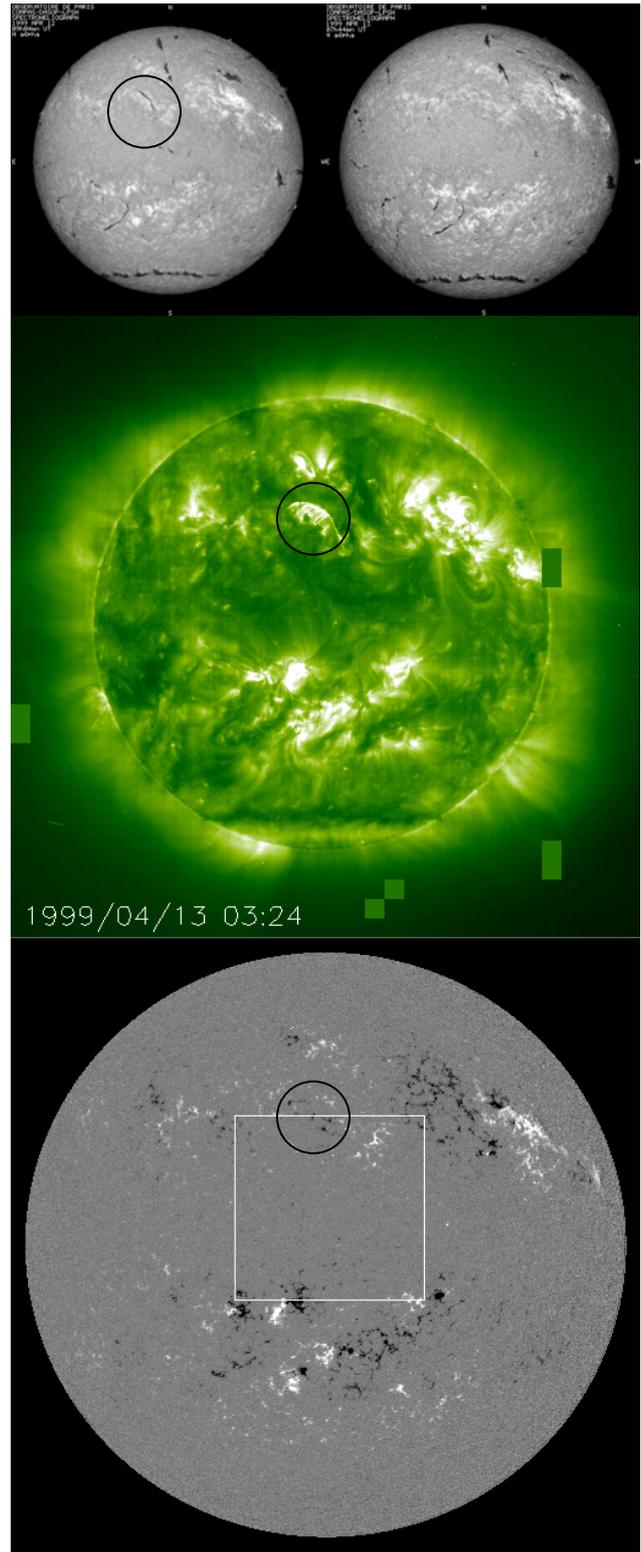


Fig. 9. Top to bottom: Disappearing filament on April 12/13, 1999; SOHO/EIT image taken at 195 Å at 03:24 UT on April 13 showing a post-eruptive arcade (circle) that developed after a frontside halo CME; MDI magnetogram taken at the same day showing the magnetic field structure of the source region.

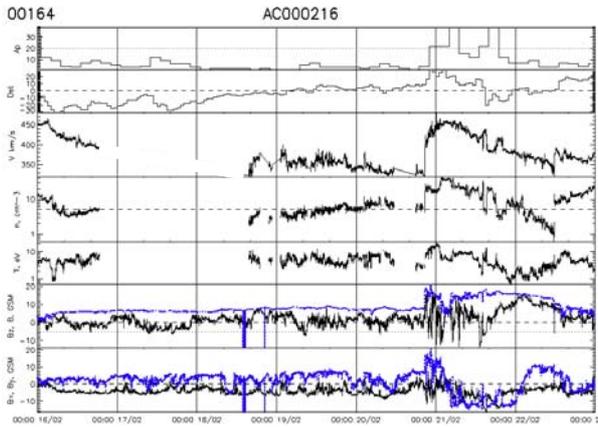


Fig. 10. A MC observed by ACE on February 21/22, 2000.

9). The LH field structure of the MC agrees with the postulated hemispheric helicity rule and the magnetic field structure of its solar source region.

Geomagnetic activity was strongest in the center of the cloud, an example for a magnetic storm triggered primarily by the southward field direction along the cloud's axis.

2.4 RH twisted SWN type MC on February 21/22, 2000

A MC passed the ACE satellite on February 21/22, 2000, preceded by a shock on February 20 (Fig. 10). The magnetic field direction is especially pronounced W to E in the B_y -component of the field vector, indicating a highly inclined cloud axis. The MVA

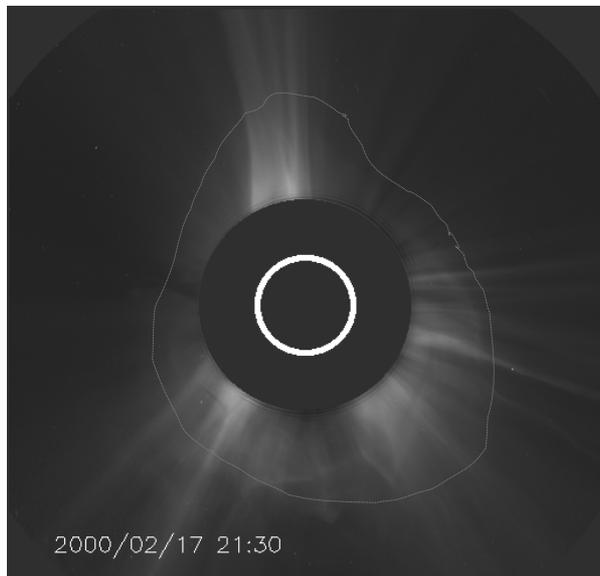


Fig. 11. The frontside halo CME on February 17, 2000 observed by SOHO/LASCO C2. The white line marks the southward centered contour of the CME.

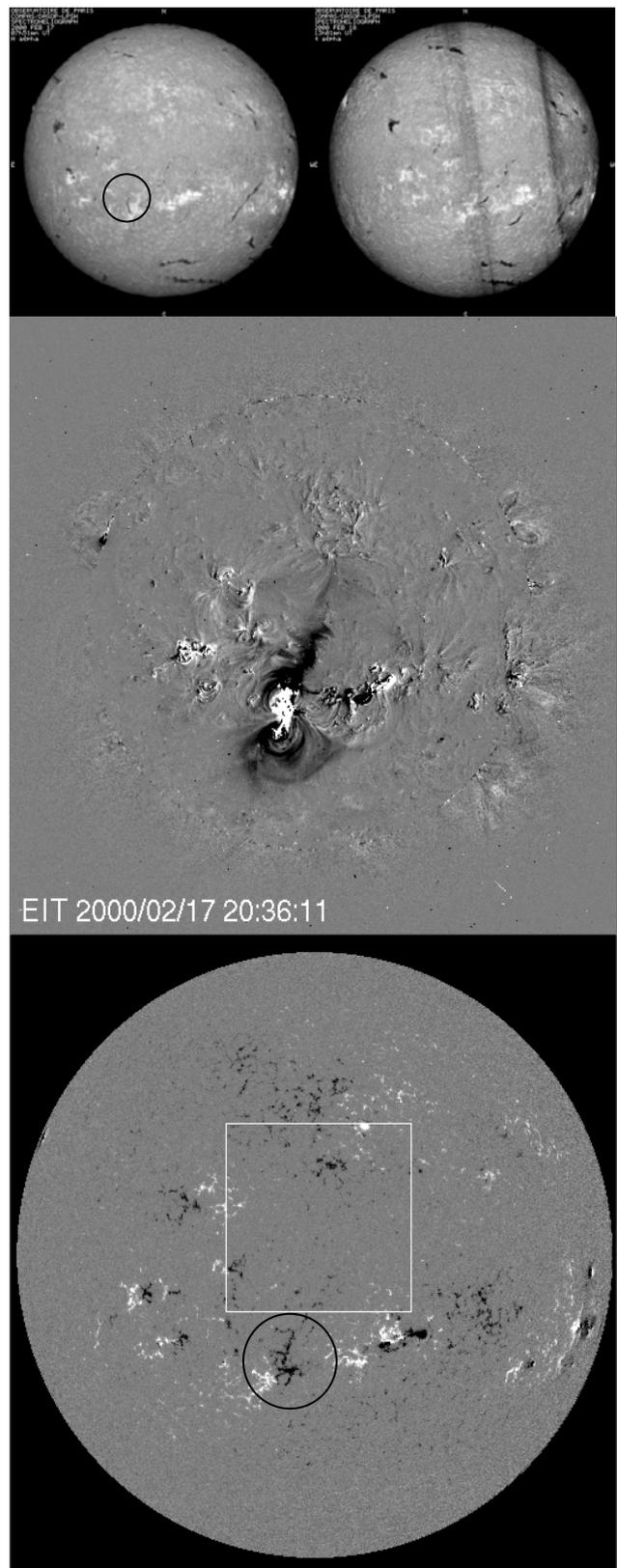


Fig. 12. Top: The disappearing filament on February 17/18, 2000. Middle: EIT 195 Å difference image showing the active region the CME lifted off from. Bottom: MDI magnetogram showing the magnetic field polarities of the solar source region.

results for the time interval February 21, 20 UT to February 22, 18 UT are consistent with this view: $\theta=+70^\circ$, $\varphi=75^\circ$. In rough agreement with the solar wind speed, a frontside halo CME centered towards the southern hemisphere was observed by LASCO/C2 on February 17, around 20 UT (Fig. 11). The associated H_α filament disappearance took place near S29°E07° (Fig. 12). The orientation of the filament's long axis was highly inclined with respect to the heliographic equator. The field configuration of the ICME was RH of type WNE, matching an inclined counter-clockwise (CCW) SWN configuration. The magnetic polarity and inclination of the neutral line of the CME source region inferred from the MDI data agree with these parameters (Fig. 12). A detailed study of the solar and interplanetary event has been presented by Yurchyshyn et al. [37].

Geomagnetic activity was highest in the sheath region ahead of the cloud, but moderate peak intensity compared to the January 10/11, 1997 MC.

2.5 LH SEN type MC on July 15/16, 2000

The strongest geomagnetic storm in solar cycle 23 was caused by an extremely fast MC detected by the Wind and ACE satellites on July 15/16, 2000. During this storm the A_p index reached its maximal possible values. Fig. 13 shows that the magnetic field rotation of the MC was LH of type SEN. The MVA for the time interval July 15, 19 UT to July 16, 09 UT yielded $\theta=+16^\circ$, $\varphi=46^\circ$. This result is roughly in agreement with that derived by Lepping et al. [38] from a MHD-modelling of the cloud's magnetic field structure yielding a stronger inclination ($\sim 55^\circ$ with respect to the ecliptic). The MC has also been studied by Yurchyshyn et al. [37] who concluded, in agreement with the MVA results, that the axis was directed almost parallel to the ecliptic plane. The source of this MC was a very fast (~ 1800 km/s) frontside halo CME on July 14 associated with a X5.7 flare and a post-eruptive arcade at central meridian observed by SOHO/EIT near N17°

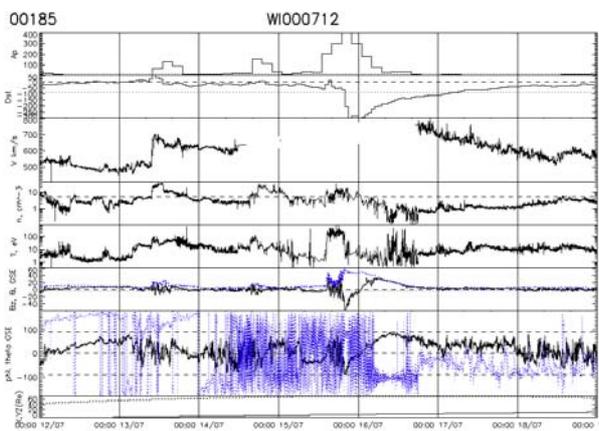


Fig. 13. A MC observed by Wind on July 15/16, 2000 and its related geomagnetic activity.

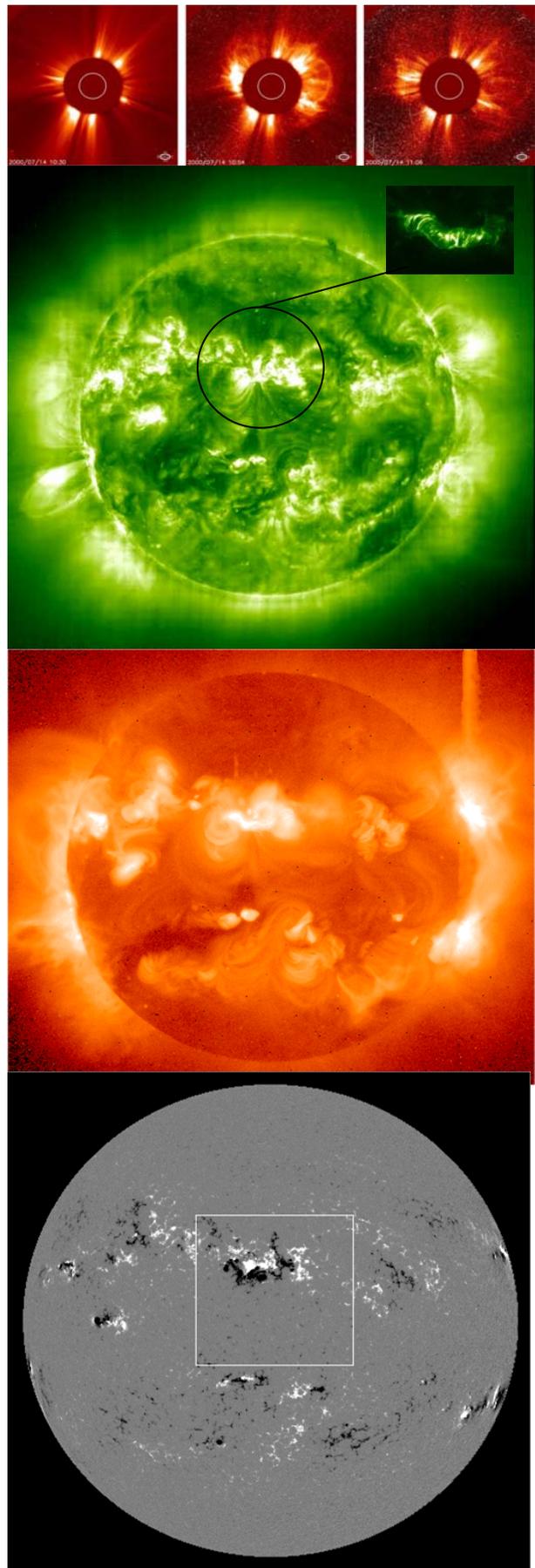


Fig. 14. Combined SOHO and Yohkoh observations of the halo CME and active region on July 14, 2000.

(Fig. 14) [39]. The orientation and magnetic polarity of the CME source region in the MDI magnetogram is in agreement with the in situ observed MC field properties: a low axis inclination, a left-handed twist and a SEN rotation of the magnetic field direction.

3. SUMMARY AND CONCLUSIONS

The interplanetary magnetic field characteristics of five magnetic clouds (helical magnetic flux rope ICMEs) detected by the Wind and ACE satellites have been investigated to infer their internal structure, space weather consequences and solar origins. The tentative results of the study can be summarized as follows:

- a) Predominantly magnetic clouds with SN rotations of the magnetic field direction were observed during the years 1996 to 2000.
- b) Magnetic clouds can occur at any orientation with respect to the ecliptic. Highly inclined clouds are not rare.
- c) Left-handed twisted magnetic clouds originated from the sun's northern hemisphere, right-handed twisted clouds originated from the sun's southern hemisphere.
- d) All of the clouds were associated with frontside halo CMEs detected by SOHO/LASCO.
- e) All CMEs originated from magnetic structures overlying magnetic polarity inversion lines in both solar hemispheres at mid to high latitudes (note that the identified source regions of magnetic clouds are contradicting suggestions that MCs stem from magnetic field regions encircling the solar equator as has been proposed in some previous studies (e.g., [41]).
- f) The in situ observed inclinations of the cloud axes were found to be in good agreement with the inclinations of the polarity inversion lines of the source regions at the sun.
- g) Most of the CMEs were associated with a disappearing filament observed in H_{α} .
- h) All of the CMEs were followed by EUV post-eruptive arcades.
- i) The speed of the halo CMEs was quite variable, in agreement with the large range of observed speeds for CMEs in general. Contrary, the ICME speeds were mostly at the order of 400-500 km/s except for the fast cloud of July 2000.
- j) The geoeffectiveness of the clouds was covering minor to major storm levels, depending on the cloud's internal magnetic field properties and propagation speeds.
- k) Magnetic clouds trigger geomagnetic storms basically in two different ways or in

combinations of these two ways: 1. through their specific internal magnetic field configuration - not only by SN or NS rotations, but also through the cloud's axis orientation when it is highly inclined and possessing a southward field direction; 2. through draping of the ambient interplanetary magnetic field (IMF) in case they drive fast shock waves ahead.

According to these results, uniquely identifiable magnetic clouds at 1 AU may be understood as "single string disturbances" that show pronounced plasma and magnetic field properties even at larger distances from the sun (≥ 1 AU). Because of their minor complexity compared to compound flows with multiple interacting streams, they can be traced back to the sun relatively straightforward allowing detailed studies of their source regions. Other single studies of MC events fit into the scheme presented here (e.g., [42]), but a systematic study of the full set of data from the Wind and ACE satellites is certainly necessary to shed more light on the long-term behavior of MCs, ICMEs, CMEs in the current solar cycle. The results presented here shall therefore not be treated as overall representative, but they definitely provide encouraging clues to help unravel further the mysteries of solar cycle helicity variations and its possible conservation, brought into the interplanetary medium via CMEs/ICMEs.

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REFERENCES

1. Klein, L.W., and Burlaga, L.F., Interplanetary Magnetic Clouds at 1 AU, *J. Geophys. Res.*, 87, 613-624, 1982.
2. Lepping, R.P., Jones, J.A., and Burlaga, L.F., Magnetic field structure of interplanetary magnetic clouds at 1 au, *J. Geophys. Res.*, 95, 11,957 – 11,965, 1991.

3. Bothmer, V., and Schwenn, R., The Structure and Origin of Magnetic Clouds in the Solar Wind, *Annales Geophysicae*, 1-24, 1998.
4. Marubashi, K., Interplanetary Magnetic Flux Ropes and Solar Filaments, *AGU Geophys. Monograph*, 99, 147-156, 1997.
5. Burlaga, L., Sittler, E., Mariani, F., and Schwenn, R., Magnetic loop behind an interplanetary shock: Voyager, Helios and IMP 8 observations, *J. Geophys. Res.*, 86, 6673-6684, 1981.
6. Burlaga, L.F., Klein, L., Sheeley, N.R. Jr., Michels, D.J., Howard, R.A., Koomen, M.J., Schwenn, R., Rosenbauer, H., A magnetic cloud and a coronal mass ejection, *J. Geophys. Res.*, 9, 1317-1320, 1982.
7. Bothmer, V. and Schwenn, R., Eruptive prominences as sources of magnetic clouds in the solar wind, *Space Sci. Rev.*, 70, 215-220, 1994.
8. Sheeley, N.R. Jr., Howard, R.A., Koomen, M.J., Michels, D.J., Schwenn, R., Mühlhäuser, K.-H., Rosenbauer, H., Coronal mass ejections and interplanetary shocks, *J. Geophys. Res.*, 90, 163-175, 1985.
9. Bothmer, V., Magnetic Field Structure and Topology Within CMEs in the Solar Wind, *Solar Wind 9 Conf. Proc.*, AIP, 119-126, 1999.
10. Bothmer, V., Schwenn, R., Signatures of fast CMEs in interplanetary space, *Adv. Space Res.*, 17, 319-322, 1996.
11. Gosling, J., Coronal mass ejections and magnetic flux ropes in interplanetary space, *AGU Geophys. Monogr.*, 58, 343-364, 1990.
12. Bothmer, V., and Schwenn, R., Signatures of fast CMEs in interplanetary space, *Adv. Space Res.*, 17, 319-322, 1996.
13. Elsässer, W.M., Hydrodynamic dynamo theory, *Rev. Mod. Phys.*, 28, 135, 1958.
14. Woltjer, L., The stability of force-free magnetic fields, *Astrophys. J.*, 128, 234, 1958.
15. Berger, M.A., and Field, G.B., The topological properties of magnetic helicity, *J. Fluid Mech.*, 147, 133, 1984.
16. Taylor, J.B., Relaxation of toroidal discharges, *Phys. Rev. Lett.*, 33, 1139, 1974.
17. Pevtsov, A.A., Canfield, R.C., Latushko, S.M., Hemispheric Helicity Trend for Solar Cycle 23, *Astrophys. J.*, 549, L261-263, 549, 2001.
18. Green, L.M., Lopez Fuentes, M.C., Mandrini, C.H., Demoulin, P., Van Driel-Gesztelyi, L., Culhane, J.L., Helicity budget of a CME-prolific active region, *Sol. Phys.*, 208, 43-68, 2002.
19. Low, B.C., Coronal mass ejections, magnetic flux ropes, and solar magnetism, *J. Geophys. Res.*, 106, 25141-25163, 2001.
20. Wilson, R.M., and Hildner, E., On the association of magnetic clouds with disappearing filaments, *J. Geophys. Res.*, 91, 5867-5872, 1986.
21. Marubashi, K., Structure of the interplanetary magnetic clouds and their solar origins, *Adv. Space Res.*, 6, 335-338, 1986.
22. Bothmer, V., and Rust, D.M., The field configuration of magnetic clouds and the solar cycle, *AGU Geophys. Monogr.*, 99, 139-146, 1997.
23. Rust, D.M., and Kumar, A., Helical magnetic fields in filaments, *Solar Phys.*, 155, 69-98, 1994.
24. Martin, S.F., Bilimoria, R., Tracadas, P.W., Magnetic field configurations basic to filament channels, in *Solar Surface Magnetism*, Springer-Verlag, 303-338, 1994.
25. Hale, G.E., Ellermann, F., Nicholson, S.B., Joy, A.H., The Magnetic Polarity of Sunspots, *Astrophys. J.*, 49, 153, 1919.
26. Mulligan, T., Russell, C. T., and Luhmann, J. G., Solar cycle evolution of the structure of magnetic clouds in the inner heliosphere, *Geophys. Res. Lett.*, 25, 2959-2962, 1998.
27. Zhang, G., and Burlaga, L.F., Magnetic clouds, geomagnetic disturbances and cosmic ray decreases, *J. Geophys. Res.*, 93, 2511-2518, 1998.
28. Ogilvie, K.W., et al., SWE, A comprehensive plasma instrument for the Wind spacecraft: The Global Geospace Mission, *Space Sci. Rev.*, 71, 55-57, 1995.
29. Lepping, R.P., et al., The Wind magnetic field investigation: The Global Geospace Mission, *Space Sci. Rev.*, 71, 207-229, 1995.
30. McComas, D.J., Bame, S.J., Barker, P., Feldman, W.C., Phillips, J.L., Riley, P., Griffee, J.W., Solar

Wind Electron Proton Alpha Monitor (SWEPAM) for the Advanced Composition Explorer, *Space Sci. Rev.*, 86, 563-612, 1998.

May 1997 magnetic cloud, *J. Geophys. Res.*, A12, 27251-27259, 2000.

31. Smith, C.W., L'Heureux, J., Ness, N.F., Acuna, M.H., Burlaga, L.F., Scheifele, J., The ACE magnetic field experiment, *Space Sci. Rev.*, 86, 613, 1998.

32. Wu, C.-C., Lepping, R.P., Gopalswamy, N., Variations of Magnetic Clouds and CMEs With Solar Activity Cycle, *these proceedings*.

33. Huttunen, K.E.J., Koskinnen, H.E.J., Schwenn, R., Properties of magnetic clouds during solar cycle 23, *Poster presentation at EGS-AGU-EUG Joint Assembly*, Nice, France, 2003.

34. Burlaga, L., Fitzenreiter, R., Lepping, R., Ogilvie, K., Szabo, A., Lazarus, A., Steinberg, J., Gloeckler, G., Howard, R., Michels, D., Farrugia, C., Lin, R.P., and Larson, D.E., A magnetic cloud containing prominence material: January 1997, *J. Geophys. Res.*, 103, 277-285, 1998.

35. Subramanian, P., and Dere, K.P., Source Regions of Coronal Mass Ejections, *Astrophys. J.*, 561, 372-395, 2001.

36. Ruzmaikin, A., Martin, S., Hu, Q., Signs of magnetic helicity in interplanetary coronal mass ejections and associated prominences: Case study, *J. Geophys. Res.*, doi:10.1029/2002JA009588, 2003.

37. Yurchyshyn, V.B., Wang, H., Goode, P.R., Deng, Y., Orientation of the Magnetic Fields in Interplanetary Flux Ropes and Solar Filaments, *Astrophys. J.*, 563, 381-388, 2001.

38. Lepping, R. P., Berdichevsky, D. B., Burlaga, L. F., Lazarus, A. J., Kasper, J., Desch, M. D., Wu, C.-C., Reames, D. V., Singer, H. J., Smith, C. W., and Ackerson, K. L., The bastille day magnetic cloud and upstream shocks: near-earth interplanetary observations, *Solar Physics*, 204, 287-305, 2001.

39. Zhang, J., Dere, K.P., Howard, R.A., Bothmer, V., Identification of Solar Sources of Major Geomagnetic Storms Between 1996 and 2000, *Astrophys. J.*, 582, 520-533, 2003.

40. Crooker, N.U., Solar and heliospheric geoeffective disturbances, *J. Atmos. Sol. Terr. Phys.*, 62, 1071-1085, 2000.

41. Webb, D.F., Lepping, R.P., Burlaga, L.F., DeForest, C.E., Larson, D.E., Martin, S.F., Plunkett, S.P., Rust, D.M., The origin and development of the